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STREAMFLOW REACTIONS OF A FIRE-DAMAGED WATERSHED

by J. D. Sinclair and E. L. Hamilton

HYDRAULICS DIVISION

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STREAMFLOW REACTIONS OF A FIRE-DAMAGED WATERSHED

J. D. Sinclair and E. L. Hamilton[1]

SYNOPSIS

A wildfire in December 1953 destroyed the brush and forest cover on portions of a watershed in the San Gabriel Mountains of southern California. Rains during January 1954 produced debris-laden flood flows from this watershed. Records of rainfall and streamflow from the partially burned watershed and from a comparable unburned drainage, before and after the 1953 fire, were analyzed. The analyses showed that peak flows and storm discharges from the damaged watershed were greatly increased by the effects of the 1953 fire. Erosion in the fire-damaged watershed is also described.

INTRODUCTION

The effects of watershed fires on streamflow and sedimentation have been discussed for centuries. An interesting example is a report by Guiseppi Paulini in 1608 to the Most Serene Prince of the Venetian Government concerning the evils of deforestation in Venice.[2] Paulini said: "The numerous and great floods, and large quantities of trash and mud which the torrents carry and deposit in the lagoon, are conditions which formerly did not exist when the mountains and valleys were covered with trees and dense forests." He concluded, "This is why I claim that the fires which for 100 years have many times denuded the mountains of Your Serenity are the principal causes of our ills."

Watershed fires in the mountains of southern California have caused "ills" similar to those reported in Venice centuries ago. The problems of flood protection and water supply in southern California arise from a combination of severe climatic and land conditions and the intensive development of the lowlands by more than 5,000,000 people.

Most of southern California has a mediterranean type climate, with little rain from April to October and usually intense rains during the fall and winter months. Rugged mountains rise abruptly from densely populated and highly developed valleys. These mountains are sources of local water supplies and, at times, disastrous floods. A mixture of shrubs, called chaparral, covers most of the mountain slopes below elevations of about 5,000 feet. Some coniferous forests occur at higher elevations. During the dry seasons the vegetation becomes highly inflammable and the danger of wildland fires is intense.

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1. Foresters, California Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agriculture in cooperation with the Univ. of California, Berkeley, Calif.
2. "The Evils of Deforestation in Venice in 1600," by Roberto Cessi and Annibale Alberti. An extract from "Un Codice Veneziano del 1600 per acque e foreste." Edited by La Libreria dello Stato, Rome, 1935.

When the mountain slopes are denuded by fire the magnitude of floods resulting from winter rains may be greatly increased.

Severe floods do not always follow fires in the mountains of southern California. Floods have not occurred during winters of deficient rainfall and gentle storms when the amount and intensity of rain falling on the denuded slopes were not great enough to produce appreciable surface runoff. On the other hand, floods have come from long unburned watersheds during prolonged and intense storms when the rain exceeded the percolation or water storage capacities of the soils and underlying rock structures in the watersheds.

The effects of watershed fires on streamflow in southern Califronia have been described by several authors in recent decades. The relation between the denudation of watersheds and debris-laden floods was reported by Munns in 1923.[3] Hoyt and Troxell in 1932 presented an analysis showing that total annual streamflow from a burned-over watershed in this region was increased, and some mention was made of increased flood flows and debris movement following the fire.[4] The disastrous La Canada Valley flood that followed a mountain fire was described by Kraebel in 1934[5] and by Troxell and Peterson in 1937.[6] Anderson and Trobitz found that forest fires, as a principal cause of differences in watershed cover, had an important effect in increasing peak discharges and erosion during the major flood of 1938.[7] That forest fires often cause higher peak discharges and sedimentation was shown in an evaluation by Anderson of fire effects for a number of watersheds.[8] Some watershed fires that were followed by floods, and others that were not, were reported by Colman in 1951.[9] A study made by Rowe, Countryman, and Storey showed that peak flows and erosion rates were increased from fire-damaged watersheds.[10]

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3. "Erosion and Flood Problems in California." Report to the Legislature in pursuance of Senate Concurrent Resolution No. 27 (1921 Legislature), by E. N. Munns, Calif. State Printing Office, Sacramento, Calif., 1923, 165 pp. illus.
4. "Forests and Stream Flow," by W. G. Hoyt and H. C. Troxell, Am. Soc. C. E., Paper No. 1858, reprinted with discussions from Transactions, Vol. 99 (1934), p. 1.
5. "The La Crescenta Flood," by Charles J. Kraebel, Am. Forests, Vol. 40, No. 6, June 1934, pp. 251-254, 286-287.
6. "Flood in La Canada Valley, Calif.," by H. C. Troxell and J. Q. Peterson, U. S. Geol. Survey Water Supply Paper 796c, 1937, pp. 53-98.
7. "Influence of Some Watershed Variables on a Major Flood," by H. W. Anderson and H. K. Trobitz, Jour. Forestry, Vol. 47, No. 5, May 1949, pp. 347-356.
8. "Flood Frequencies and Sedimentation from Forest Watersheds," by Henry W. Anderson, Transactions, Am. Geophysical Union, Vol. 30, No. 4, August 1949, pp. 567-584.
9. "Fire and Water in Southern California's Mountains," by E. A. Colman, Misc. Paper No. 3, Calif. For. and Range Exp. Sta., Forest Service, U. S. Dept. of Agriculture, June 25, 1951.
10. "Hydrologic Analysis Used to Determine Effects of Fire on Peak Discharge and Erosion Rates in Southern California Watersheds," by P. B. Rowe, C. M. Countryman, and H. C. Storey, Calif. For. and Range Exp. Sta., Forest Service, U. S. Dept. of Agriculture, 1953, manuscript report.

Similar effects of two watershed fires on flood flows and erosion were described by the staff of the San Dimas Experimental Forest.[11]

Although a number of floods following watershed fires have been reported, information concerning both watershed conditions and flood flows before and after the fires has usually been incomplete. In this report streamflow reactions of two watersheds in the San Gabriel Mountains of southern California are compared before and after one was partially burned-over in December 1953. Here unusually complete data are available since the watersheds are part of the San Dimas Experimental Forest and have been under close observation for nearly 20 years.

The Watersheds

The San Dimas Experimental Forest[12] was established in 1933 by the Forest Service of the U. S. Department of Agriculture for hydrologic research in the brush-covered wild lands of the region. As a part of this research program intensive records of rainfall and streamflow have been obtained from 17 watersheds comprising the Experimental Forest for a period of nearly 20 years. Low clear flows from the respective watersheds are measured through 90-degree V-notch weirs. Stormflows carrying bed load are measured through San Dimas flumes specially designed for measurement of debris-laden flows.[13] Rainfall is sampled by a network of gages located at 1,000-ft. altitudinal levels. Rainfall rates are determined by self-registering gages, one near the stream-gaging station and the other in the headwaters of each watershed.

The watersheds under discussion are: I—Wolfskill Canyon, and III—Upper East Fork of San Dimas Canyon, both tributaries to the San Dimas drainage (Fig. 1). The area and range in elevation of each are as follows:

Watershed	Drainage area		Range in elevation
	Sq. mi.	Acres	Feet
I—Wolfskill	2.38	1,525	1,700-5,200
III—Upper East Fork	2.14	1,375	2,600-5,200

Both drainages are within an area of rugged relief, with steep slopes between sharp ridges and deep canyons (Fig. 2 and 3). Aspects are similar because the flow pattern of the main streams is southwesterly.

The rocks underlying the watersheds are primarily metamorphic, consisting largely of gneisses and schists. Many dikes of igneous material have been injected through the rocks. A large mass of granodiorite occurs in watershed I and a smaller body of quartzdiorite in watershed III. Both metamorphic and granitic rock types are deeply fractured and weathered. Soils are mostly

11. "Fire-Flood Sequences on the San Dimas Experimental Forest," by the Staff of the San Dimas Experimental Forest, Tech. Paper No. 6, Calif. For. and Range Exp. Sta., Forest Service, U. S. Dept. of Agriculture, March 1954, 29 pp., illus.
12. "A Guide to the San Dimas Experimental Forest," by J. D. Sinclair and E. L. Hamilton, Misc. Paper No. 11, Calif. For. and Range Exp. Sta., Forest Service, U. S. Dept. of Agriculture, 1953, 19 pp.
13. "Measurement of Debris-Laden Stream Flow with Critical-Depth Flumes," by H. G. Wilm, John S. Cotton, and H. C. Storey, Am. Soc. C. E., Paper No. 2005, reprinted from Transactions, Vol. 103 (1938), p. 1237.

rocky and gravelly sands and sandy loams, usually shallow and very unstable. On the steep slopes soil movement has precluded the development of distinct soil horizons.

The vegetation on both watersheds was similar before the partial burning of watershed I in 1953. It was typical of the brush and forest cover at comparable elevations on the southern slope of the San Gabriel Mountains. Brush, or chaparral, types occupied 53 percent of the area in each watershed. Woodland, consisting principally of oak with some alder and maple along the streams, occurred on 22 percent of watershed I and 27 percent of watershed III. Bigcone Douglas-fir (locally called bigcone spruce) forest covered 14 percent of each watershed. Semi-barren areas on the steep canyon walls, mostly in the lower portions of the watersheds, occurred on 11 percent of watershed I and 6 percent of watershed III.

Fire History

There is no definite record of fire in watershed I before 1953. The first recorded fire in watershed III occurred in 1919. At that time the vegetation was destroyed on 28 acres along the western boundary of the drainage. Another fire, in 1938, burned 45 acres in the southeastern headwaters of this watershed.

During 1953 wildfires burned the brush and forest cover on more than 170,000 acres in southern California, the greatest loss of watershed cover in more than 20 years. The usual summer and fall fire season was intensified and prolonged by severe drought. In December during periods of strong, dry winds, two major fires burned-over some 20,000 acres in the San Gabriel Mountains. One, the Barrett fire, spread into the San Dimas Experimental Forest during the night of December 27, burning the vegetation on more than 500 acres in the San Dimas drainage (Fig. 1). In watershed I the fire covered 31.6 percent of the area, or 483 acres, of which 278 acres were severely burned and 205 partially burned (Fig. 2). Thus the stage was set for possible floods from watershed I in the San Dimas Forest and from other drainages in the region damaged by fire in 1953.

Events During January 1954

To insure that the best possible records be obtained in case of severe storms, special provisions were made soon after the 1953 fire at the watershed I streamgaging station. This gaging station, like the station at watershed III, is equipped with two San Dimas flumes (3 and 10 feet in width) for measurement of moderate to high flows carrying bed load, and a V-notch weir for measurement of low clear flows (Fig. 4A). A dual system of water-stage recorders for the large flume at station No. I was installed to aid in the measurement of anticipated flood flows. Further, arrangements were made to have two field observers on duty at the station during storms, and floodlights were rigged to facilitate operations at night.

The fire was not completely out when the first post-fire storm occurred on January 11 and 12. Precipitation, mostly snow above 3,000 feet, during this small storm amounted to less than 1 inch on watersheds I and III (Table 1). Rainfall rates were low in both drainages (Table 2). The storm assured final control of the fire and produced negligible flows through the gaging stations.

A second post-fire storm, in the 3-day period January 17 to 20, produced an average of 5.98 inches of rain on watershed I and 7.21 inches on watershed

III (Table 1). During this large storm, short-time rainfall rates were high in both watersheds; however, the 5-minute rate was slightly higher in watershed III than in I (Table 2). Streamflow at the watershed I gaging station was spectacular, and caused the field observers there to question whether "to run for high ground or stay and try to get records."

The flow at No. I gaging station which had been about 1 c.f.s. on January 18, the first day of the storm, rose shortly after midnight to 30 c.f.s., then fluctuated between 20 and 40 c.f.s. for 3 hours. At 0438 on January 19 a flood wave of water, mud, logs, and rocks 6 1/2 feet deep roared through the 10-foot wide flume at this station (Fig. 4B). Bulked with debris, this wave reached a peak flow of 1,025 c.f.s. and was followed by a flow of 700 c.f.s. that persisted for about 10 minutes. Logs and boulders were tossed about, stilling wells were filled with sand, and the observers were forced to continue the record by frequent staff-gage observations.

Four days of fair weather followed the second storm, permitting emergency repairs to the No. I gaging station. Then early on January 24 a third storm hit. Again the precipitation was mostly rain, although a small amount of snow fell during the final passage of the storm front. This storm brought an average of 6.15 inches of rain on watershed I and 4.82 inches on watershed III (Table 1). Rainfall rates during the January 24-25 storm also were much higher in watershed I than in III, the maximum 5-minute rate in I being 2.52 inches per hour compared to .96 inches per hour in III (Table 2). Streamflow reactions of watershed I were much the same as in the preceding storm. The flow rose from 0.5 c.f.s. on January 23 to 8 c.f.s. early on January 24, then to 145 c.f.s. and finally a flood wave, this time only 5 feet deep, and equivalent to 710 c.f.s., went through the watershed I gaging station.

Meanwhile in watershed III and in other parts of the Experimental Forest undamaged by fire, streamflow peaks had been moderate and the flows mostly clear. Streamflow reactions in watershed I obviously had been very different from those in watershed III.

During the large storms of January 17-20 and 24-25, floods came also from other watersheds burned-over by the fires of 1953 in southern California. Downstream developments in the paths of these debris-laden flood flows were destroyed or severely damaged in several localities.

Streamflow Reactions

Analyses were conducted to determine the effects of the 1953 fire in watershed I on (a) peak flows[14] and (b) storm discharges[15] from this damaged watershed. Hydrographs also were developed to demonstrate the streamflow reactions of watershed I caused by the 1953 burn.

Peak Flows.—Double mass analysis was used to show the relation between peak flows from watersheds I and III before and after the 1953 fire. Accumulated peak flows were plotted for 290 storms during 18 years (Fig. 5). For 17 years before the 1953 fire a fairly constant relation existed between peak flows from these watersheds. Then during January 1954 this relation changed abruptly. The slope of the line in the graph increased from 0.8 to 36.3, a change which is obviously significant.

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14. Maximum rate of streamflow and entrained debris, in c.s.m. (cubic feet per second per square mile), during a storm.
15. Total volume of streamflow and entrained debris, in acre-feet per square mile, occurring between the time a flow was increased by a storm and the time a flow decreased to approximately the pre-storm rate.

The double mass graph included peak flows for all sizes and conditions of storms. A more specific basis for the determination of burn effects in watershed I was obtained by selecting a sample composed of pre-fire storms that produced peak flows ranging from 1/2 to 2 times the size of the peaks from watershed III, the control, after the fire. Further, the sample pre-fire storms were limited to those ranging from 1/4 to 1 1/2 times the size of the storms after the fire. The peak flows of the two watersheds were plotted as a scatter diagram and a line was fitted to the points by the method of least squares (Fig. 6). The equation for this line is:

$$I = -0.929 + 0.798\ III \qquad (1)$$

where I is the peak flow from watershed I in c.s.m., and III is the peak flow from watershed III in c.s.m. The standard error of estimate for the equation is 2.11.

If watershed I had not been damaged by fire, expected peak flows from the watershed during the storms of January 17-20 and 24-25, 1954, computed by equation (1), would have been 3.36 and 10.46 c.s.m. respectively, a highly significant difference from the observed peaks of 429 and 297 c.s.m. These results indicate that the peak flow during the first storm was 128 times as great as, and during the second storm 28 times as great as expected had watershed I not been partially burned. The greater increase during the first storm was due in part to the flood wave that occurred. Remnants of log jams found later in the channel of watershed I are evidence that the flow was held back temporarily and then released as a surge when the log jams were broken. The flows during both storms were bulked with debris although there was less debris in the flow during the second storm.

Storm Hydrographs.—Hydrographs were prepared to compare stormflows from watersheds I and III before and after the 1953 fire. Hydrographs for the two large storms in January 1954, prepared on a time scale of 15-minute intervals, indicate graphically the reactions of the post-fire flows to rainfall rates (Fig. 7). As noted previously, rainfall during the first storm amounted to 5.98 inches in watershed I and 7.21 inches in watershed III; during the second storm the amounts were 6.15 and 4.82 inches respectively. Runoff from watershed I fluctuated widely and rose to high peaks after each period of prolonged or intense rainfall. In contrast, the runoff from watershed III rose gradually and reached relatively insignificant peaks during both storms, and the peaks were from 2 to 2 1/2 hours later than the peaks from watershed I.

That such wide divergence in stormflow reactions of the watersheds are not customary was shown by hydrographs prepared for two pre-fire storms (Fig. 8). During the storm of November 11-13, 1944 (Fig. 8A), rainfall in watershed I amounted to 10.78 inches and in watershed III, 10.11 inches. The storm of December 21-24, 1945 (Fig. 8B) brought 12.16 inches of rain in watershed I and 11.89 inches in watershed III. These storms were selected as being similar to the January 1954 storms in time of occurrence during the rainy season and in amount of prior rainfall, but greater in amount and rate of rainfall. The hydrographs for these two storms indicate that streamflow behavior of the two watersheds was similar before the fire, both as to quantity and reaction time. This similarity was a marked contrast to the great differences in streamflow after the fire.

To determine quantitatively the effects of the 1953 fire on storm discharges from watershed I, an analysis was made that included a series of 18 storms occurring during the 17 years of record before the fire. This sample of storms coincided generally with the storms used in the previous analysis of

peak flows. Pre-fire storm discharges from watershed I were plotted over corresponding values for watershed III and a line fitted to the points by the method of least squares (Fig. 9). The equation for this line is:

$$I = 2.005 + 0.648\ III \qquad (2)$$

where I is the storm discharge from watershed I and III is the storm discharge from watershed III, both discharges expressed in acre-feet per square mile. The standard error of estimate for the equation is 4.39.

Had watershed I not been partially burned the expected discharges during the two January storms, computed from Equation (2), would have been 6.09 and 10.95 acre-feet per square mile respectively. The comparable observed discharges from watershed I, plotted in Figure 9 as black dots, were 31.40 and 32.90 acre-feet per square mile. The differences between calculated and observed flows are significant at the 1-percent level. Thus the discharges from the fire-damaged watershed are shown to have been 5.2 times as great as expected during the first large post-fire storm and 3.0 times as great as expected during the second large storm, had the watershed not been partially burned.

Although storm discharges from the fire-damaged watershed were increased, the flows were bulked with unknown quantities of debris. Therefore the water content of the flows was less than indicated by records of total storm discharges.

Erosion After the 1953 Fire

Sediment production from watersheds I and III could not be measured because the watersheds are not equipped with catchment basins. However, based upon field observations after the storms of January 1954, it was estimated that soil and weathered rock materials averaging at least 0.6 of an inch in depth had been washed from the slopes by sheet and rill erosion within the burned area of watershed I. An additional 3,000 cubic yards of matetial were estimated to have been removed from the burn by bank cutting and scouring in small headwater channels of the watershed. These estimates indicate that at least 42,000 cubic yards of material were eroded from the 483-acre burn in watershed I, representing a rate of 55,000 cubic yards per square mile.[11] Erosion was negligible in watershed III and in the other unburned watersheds within the San Dimas Experimental Forest.

Flood runoff from the burned area in watershed I also caused severe bank cutting and channel scouring in the main stream course for about 2 miles below the burn. As the debris-laden flows receded, large deposits of eroded material were left in some sections of the channel in watershed I and downstream, from the mouth of the watershed to San Dimas Reservoir. These channel deposits and other material coming from the burned area will increase sedimentation in San Dimas Reservoir, thereby reducing storage capacity for flood regulation and water conservation.

Summary and Conclusions

Wildfires severely damaged the vegetation on 170,000 acres of southern California mountain watersheds in 1953. Previous experience has indicated that severe floods can result from heavy rainfall on newly fire-denuded mountain slopes. Flood flows from the recently burned areas actually occurred in January 1954, causing much damage to residential developments near the foothills by high water and debris movement.

On the San Dimas Experimental Forest, a watershed 2.4 square miles in area had about one-third of its vegetation destroyed by a wildfire in December 1953. Analysis of rainfall and streamflow records collected currently and during the past 17 years from this watershed and from an adjacent undamaged watershed permitted comparisons of streamflow reactions of the two watersheds before and after the fire. The relation of peak flows between the two watersheds, which had been fairly constant before the fire, was upset, and the peak flows from the fire-damaged watershed reached a maximum 128 times as great as expected had the watershed been unburned. Total storm discharges were three to five times as great as expected as a result of the burn. Stormflows from the damaged watershed were bulked with debris washed from the burned slopes and the stream channels below them. At the same time flows from the unburned watershed were comparatively clear.

Three conclusions can be drawn from the results of this study:

1. The abnormally large peak flows bulked with debris from fire-damaged watersheds complicate problems of flood control in southern California. The cost and difficulty of flood control is increased when watersheds are burned, as indicated by the size and destructive power of the flows which, bulked with debris, pour from the burned lands during heavy storms. Further, the debris washed from burned watersheds reduces the storage capacity of reservoirs, impairing their usefulness for flood control and water conservation.

2. The increased volume of storm discharges from the fire-damaged watershed is not an accurate measure of increased water yield because the flows were bulked with unknown quantities of debris.

3. Adequate wild-land fire protection in the mountains of southern California will aid in the regulation of flood flows and debris movement.

Acknowledgment

Acknowledgment is due to L. F. Reimann for his assistance with the analyses of data presented in this paper.

Table 1.--Rainfall during January 1954 on watersheds I and III

Date	Watershed number			
	I		III	
	Recording gage 3,600 ft. elevation	Average of 12 standard gages1/	Recording gage 4,350 ft. elevation	Average of 9 standard gages1/
	Inches			
January 11	.04	.04	.04	.03
January 12	.91	.85	.77	.82
Storm total	.95	.89	.81	.85
January 17	.01	0	.04	.03
January 18	1.76	1.64	1.57	1.55
January 19	4.47	4.19	5.20	5.56
January 20	.12	.15	.05	.07
Storm total	6.36	5.98	6.86	7.21
January 24	4.29	4.02	3.46	3.61
January 25	2.26	2.13	1.15	1.22
Storm total	6.55	6.15	4.61	4.82
Total (3 storms)	13.86	13.02	12.28	12.88

1/ Total rainfall for the three storms measured in all gages. Daily rainfall and individual storm totals for standard gages prorated from recording gage records.

Table 2.—Rainfall rates in watersheds I[1/] and III[2/]

Storm date	Watershed number	Duration (minutes)				
		5	15	30	60	360
		Inches per hour				
Jan. 11-12, 1954	I	.48	.24	.26	.23	.10
	III	.24	.28	.28	.26	.10
Jan. 17-20, 1954	I	1.32	1.08	.90	.64	.40
	III	1.68	1.00	.74	.63	.50
Jan. 23-25, 1954	I	2.52	2.40	1.54	.79	.49
	III	.96	.64	.60	.48	.27

1/ Recording gage at 3,600-ft. elevation.
2/ Recording gage at 4,350-ft. elevation.

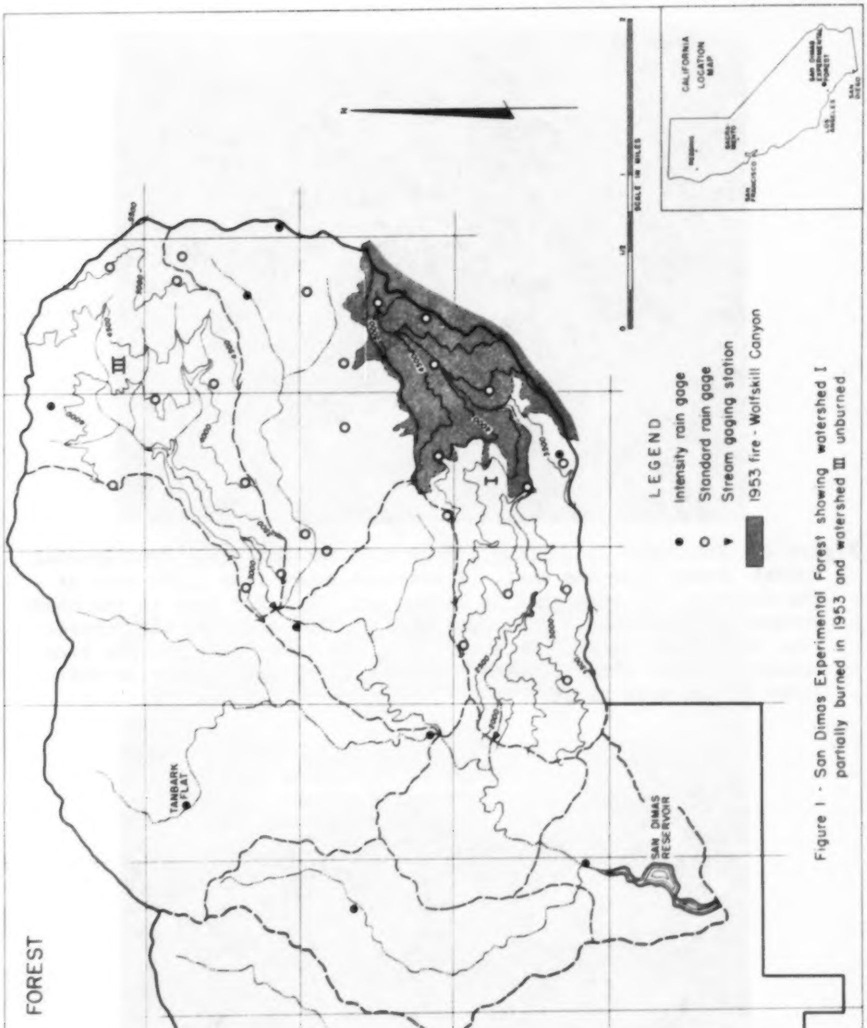


Figure 1 - San Dimas Experimental Forest showing watershed I partially burned in 1953 and watershed III unburned

Figure 2.- Watershed I, Wolfskill Canyon of the San Dimas Experimental Forest viewed from the east. Elevations range from 1,700 feet at the mouth of the watershed in background, to 5,200 feet at the headwaters in foreground. The upper part of the watershed was burned-over during the fire of December 1953; the lower part has not been burned for more than 50 years. Cleared firebreaks appear as white lines on the main ridges.

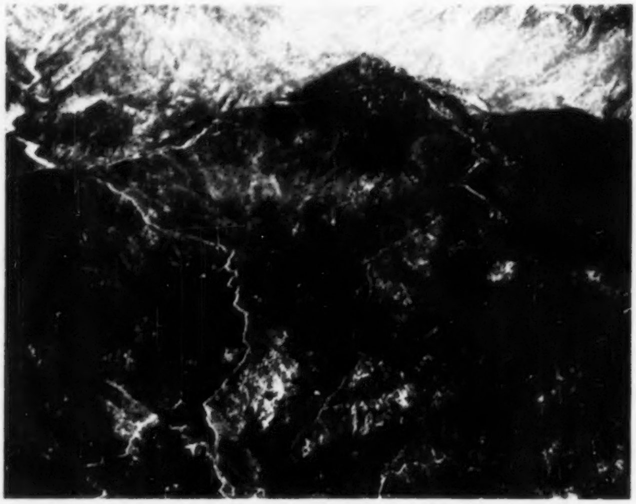
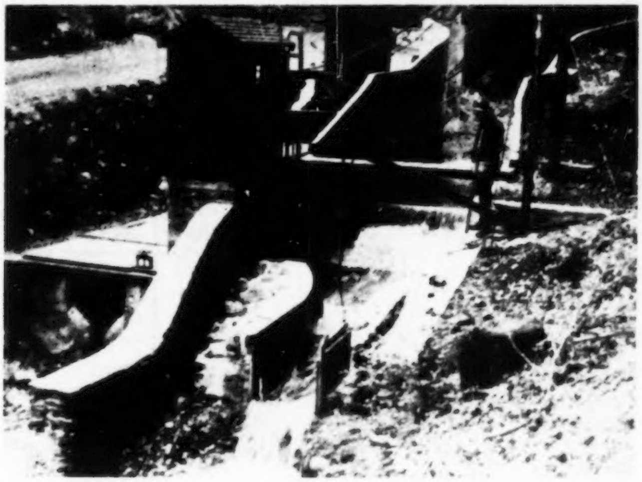
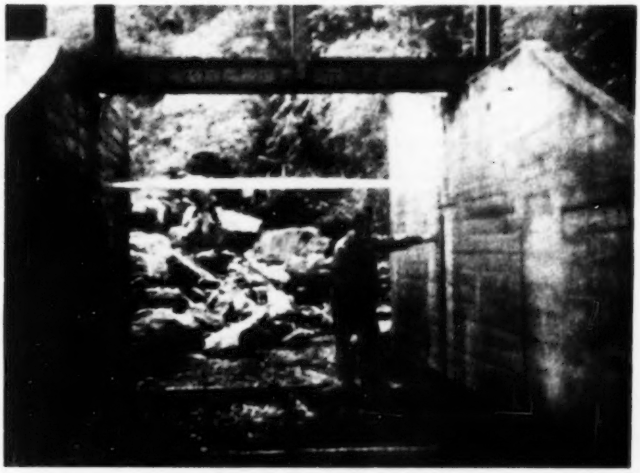


Figure 3.- Watershed III, the Upper East Fork of San Dimas Canyon, is the middle drainage viewed from the southwest. Elevations in the watershed range from 2,600 feet to 5,200 feet. Most of the vegetation on this watershed has not been burned for more than a half century.



A



B

Figure 4.- Streamgaging station at the mouth of watershed I. A: San Dimas flumes 3 feet and 10 feet in width, at right, are used to measure flows carrying debris. Low clear flows are diverted through weir at left. Approach to large flume in background was unobstructed in 1941. B: After the January 1954 storms the approach to the large flume was covered with boulders and other debris deposited during the flood flows. The height of the maximum flow in the 10-foot flume is indicated by the cloth strip.

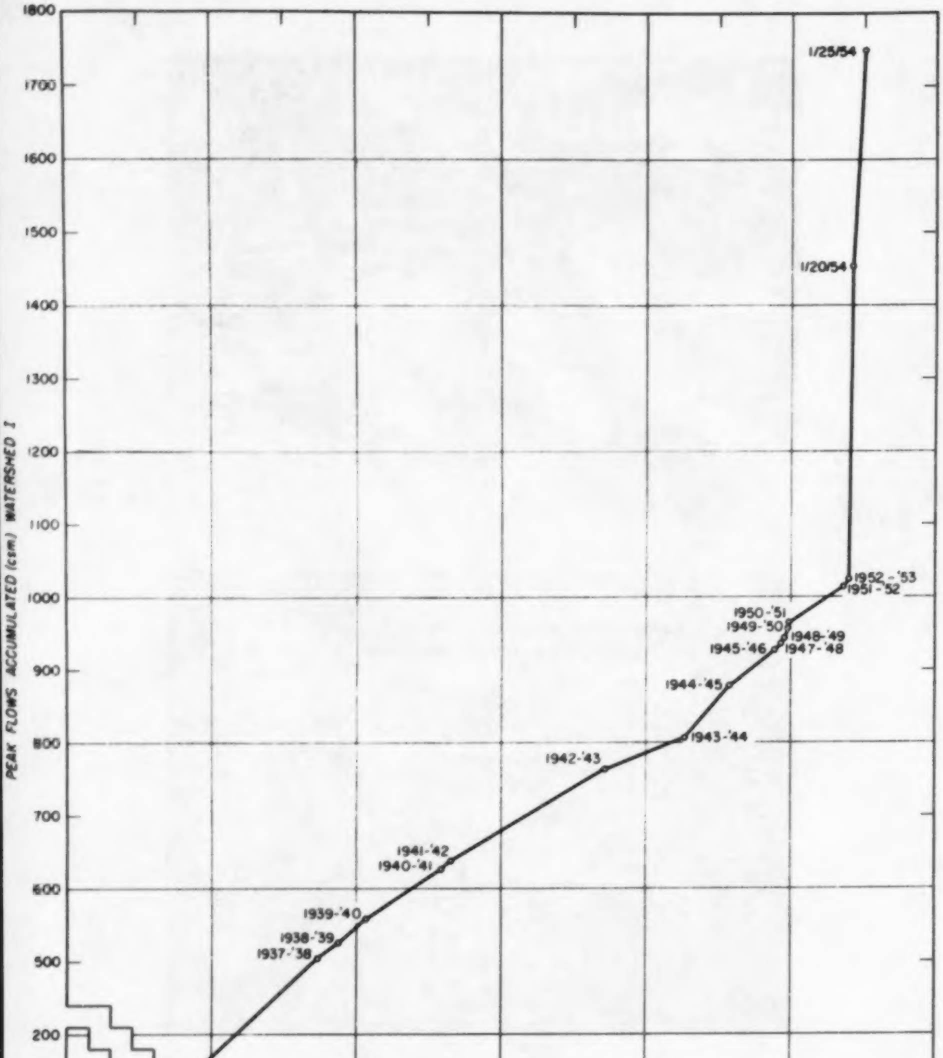


Figure 5 - Relation of accumulated peak flows from watershed I to accumulated peak flows from watershed III before and after 1953 fire.

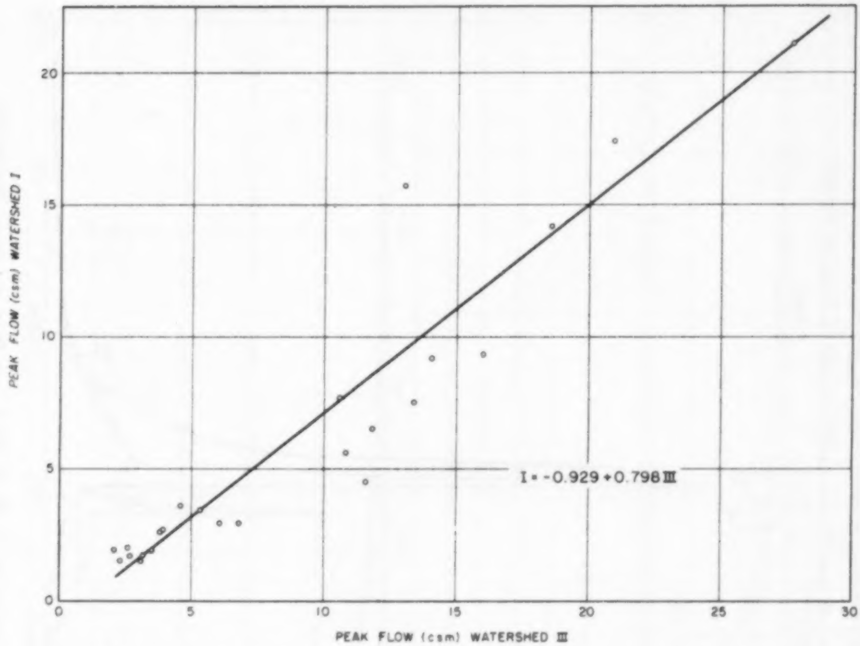


Figure 6 - Relation of peak flows from watershed I to peak flows from watershed III before 1953 fire.

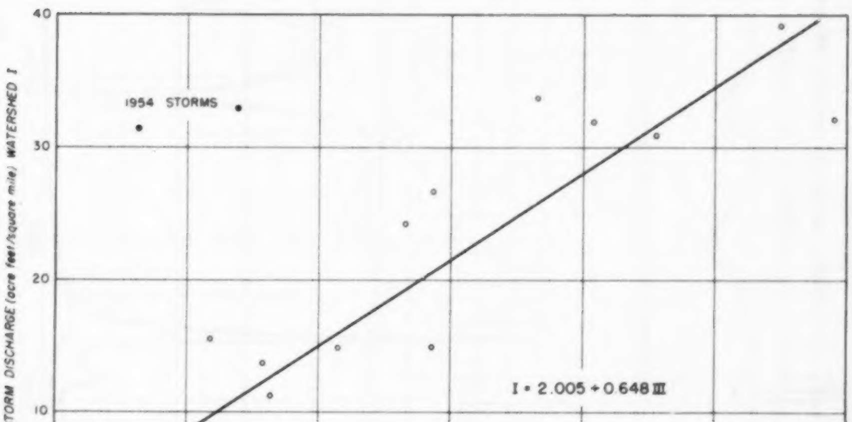


Figure 9 - Relation of storm discharge from watershed I to storm discharge from watershed III before and after 1953 fire.

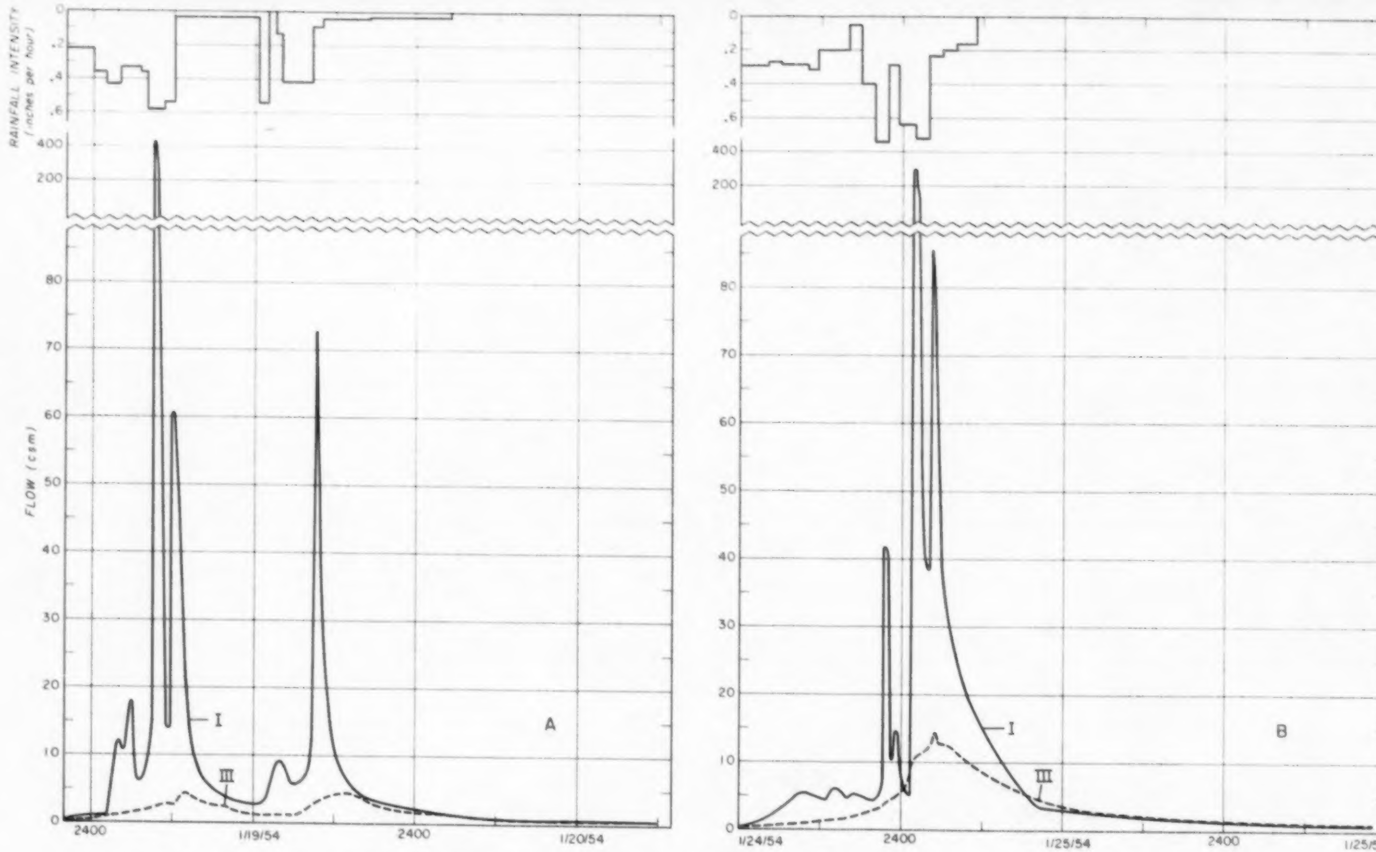


Figure 7 - Storm hydrographs for watersheds I and III after 1953 fire. A. Storm of January 18-20, 1954. B. Storm of January 24-25, 1954.

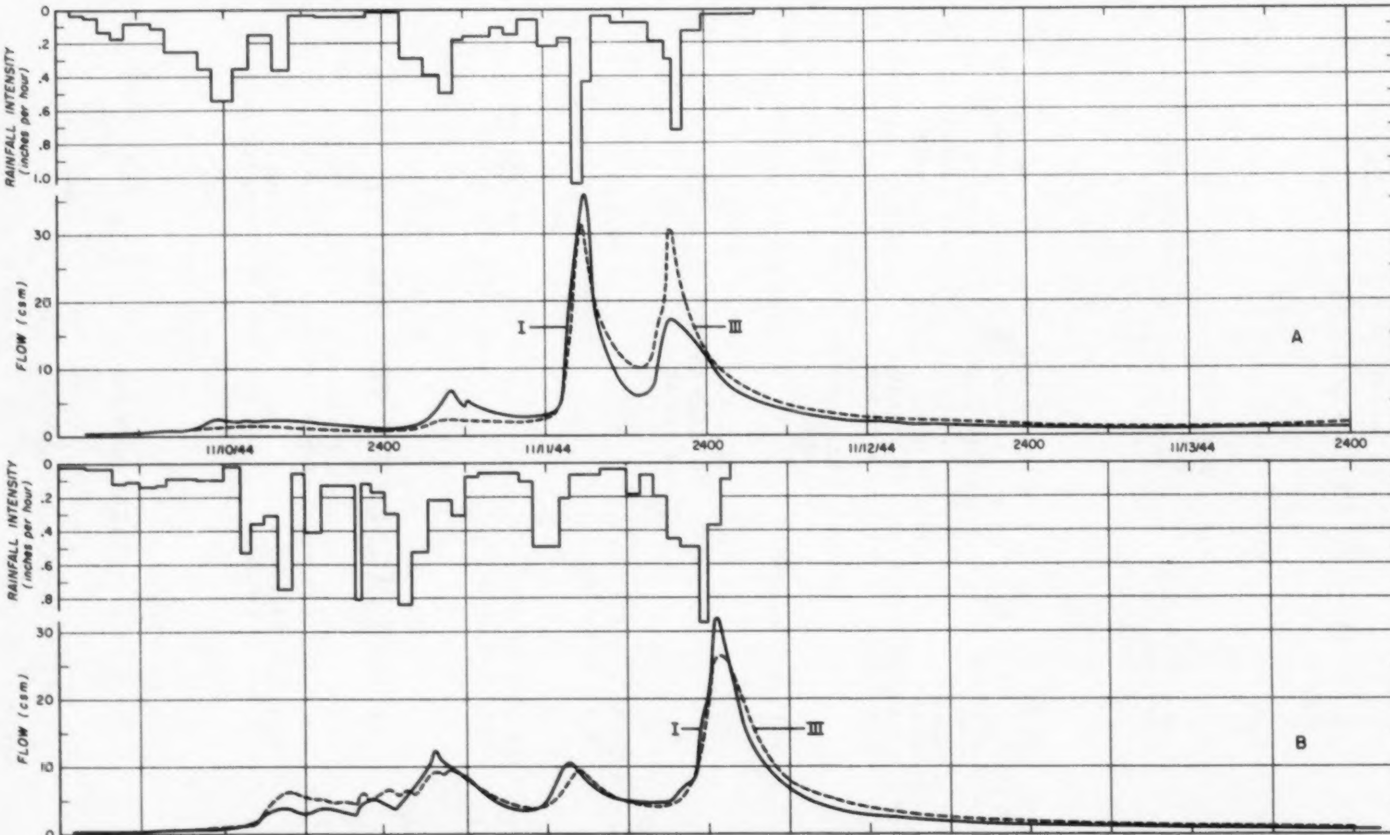


Figure 8 - Storm hydrographs for watersheds I and III with watershed vegetation undamaged. A. Storm of November 10-13, 1944. B. Storm of December 21-24, 1945.